

William Stallings

Data and Computer

Communications

7th Edition

Chapter 5

Signal Encoding Techniques

Encoding Techniques

- Digital data, digital signal
- Analog data, digital signal
- Digital data, analog signal
- Analog data, analog signal

Digital Data, Digital Signal

- Digital signal
 - Discrete, discontinuous voltage pulses
 - Each pulse is a signal element
 - Binary data encoded into signal elements

Terms (1)

- Unipolar
 - All signal elements have same sign
- Polar
 - One logic state represented by positive voltage the other by negative voltage
- Data rate
 - Rate of data transmission in bits per second
- Duration or length of a bit
 - Time taken for transmitter to emit the bit

Terms (2)

- Modulation rate
 - Rate at which the signal level changes
 - Measured in baud = signal elements per second
- Mark and Space
 - Binary 1 and Binary 0 respectively

Interpreting Signals

- Need to know
 - Timing of bits - when they start and end
 - Signal levels
- Factors affecting successful interpreting of signals
 - Signal to noise ratio
 - Data rate
 - Bandwidth

Comparison of Encoding Schemes (1)

- Signal Spectrum
 - Lack of high frequencies reduces required bandwidth
 - Lack of dc component allows ac coupling via transformer, providing isolation
 - Concentrate power in the middle of the bandwidth
- Clocking
 - Synchronizing transmitter and receiver
 - External clock
 - Sync mechanism based on signal

Comparison of Encoding Schemes (2)

- Error detection
 - Can be built in to signal encoding
- Signal interference and noise immunity
 - Some codes are better than others
- Cost and complexity
 - Higher signal rate (& thus data rate) lead to higher costs
 - Some codes require signal rate greater than data rate

Encoding Schemes

- Nonreturn to Zero-Level (NRZ-L)
- Nonreturn to Zero Inverted (NRZI)
- Bipolar -AMI
- Pseudoternary
- Manchester
- Differential Manchester
- B8ZS
- HDB3

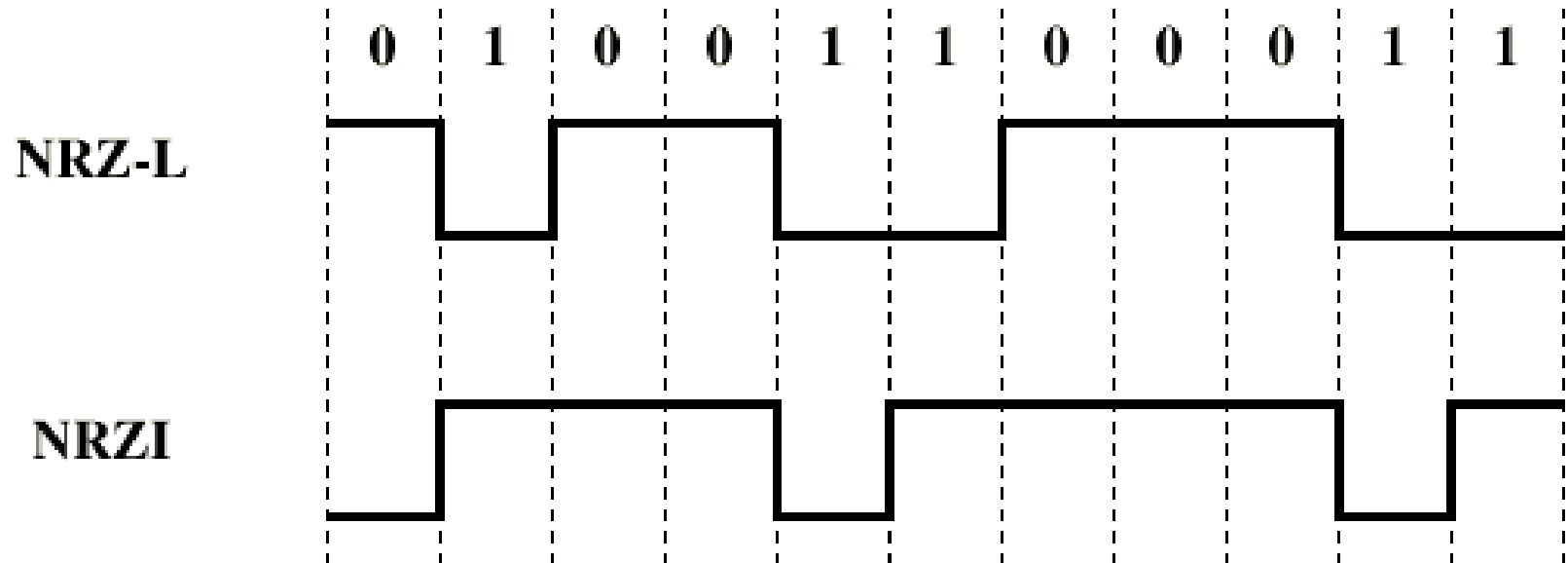
Nonreturn to Zero-Level (NRZ-L)

- Two different voltages for 0 and 1 bits
- Voltage constant during bit interval
 - no transition I.e. no return to zero voltage
- e.g. Absence of voltage for zero, constant positive voltage for one
- More often, negative voltage for one value and positive for the other
- This is NRZ-L

Nonreturn to Zero Inverted

- Nonreturn to zero inverted on ones
- Constant voltage pulse for duration of bit
- Data encoded as presence or absence of signal transition at beginning of bit time
- Transition (low to high or high to low) denotes a binary 1
- No transition denotes binary 0
- An example of differential encoding

NRZ



Differential Encoding

- Data represented by changes rather than levels
- More reliable detection of transition rather than level
- In complex transmission layouts it is easy to lose sense of polarity

NRZ pros and cons

- Pros
 - Easy to engineer
 - Make good use of bandwidth
- Cons
 - dc component
 - Lack of synchronization capability
- Used for magnetic recording
- Not often used for signal transmission

Multilevel Binary

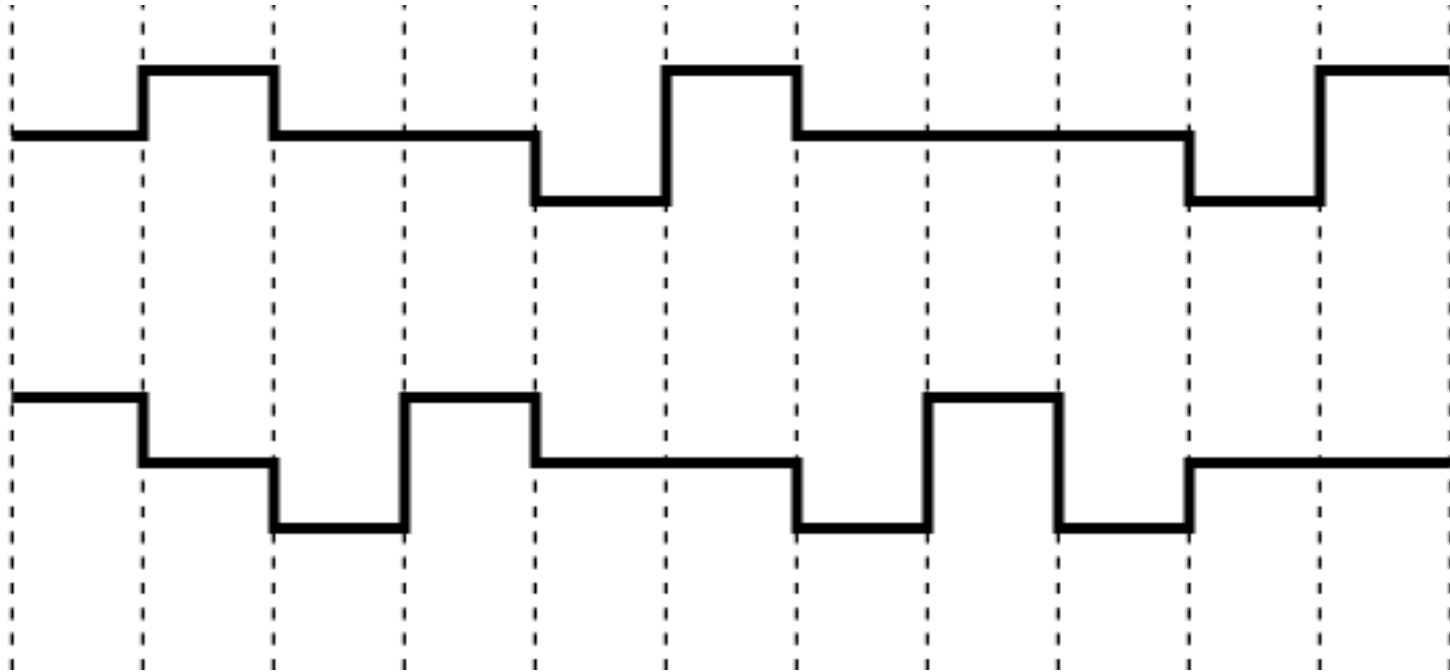
- Use more than two levels
- Bipolar-AMI
 - zero represented by no line signal
 - one represented by positive or negative pulse
 - one pulses alternate in polarity
 - No loss of sync if a long string of ones (zeros still a problem)
 - No net dc component
 - Lower bandwidth
 - Easy error detection

Pseudoternary

- One represented by absence of line signal
- Zero represented by alternating positive and negative
- No advantage or disadvantage over bipolar-AMI

Bipolar-AMI and Pseudoternary

Bipolar-AMI
(most recent
preceding 1 bit has
negative voltage)



Pseudoternary
(most recent
preceding 0 bit has
negative voltage)

Trade Off for Multilevel Binary

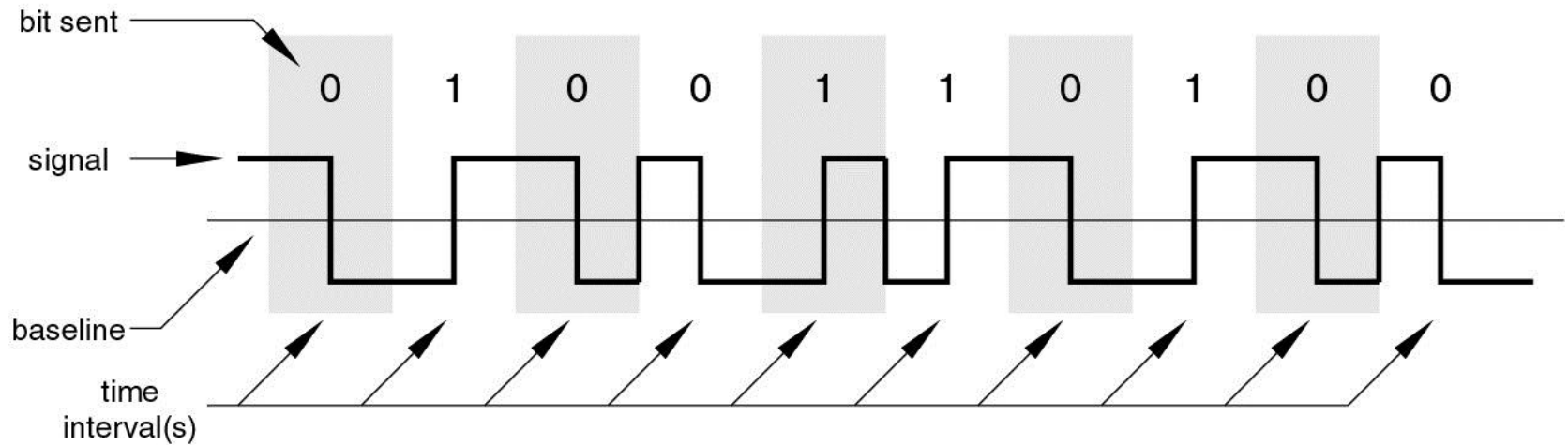
- Not as efficient as NRZ
 - Each signal element only represents one bit
 - In a 3 level system could represent $\log_2 3 = 1.58$ bits
 - Receiver must distinguish between three levels
(+A, -A, 0)
 - Requires approx. 3dB more signal power for same probability of bit error

Biphase

- Manchester
 - Transition in middle of each bit period
 - Transition serves as clock and data
 - Low to high represents one
 - High to low represents zero
 - Used by IEEE 802.3
- Differential Manchester
 - Midbit transition is clocking only
 - Transition at start of a bit period represents zero
 - No transition at start of a bit period represents one
 - Note: this is a differential encoding scheme
 - Used by IEEE 802.5

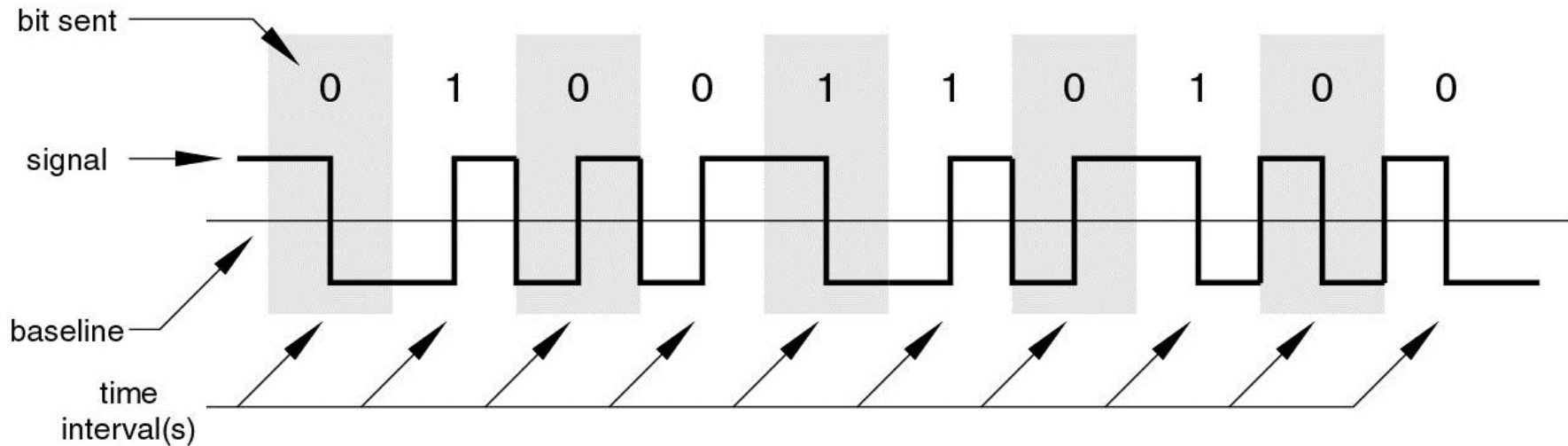
Manchester Encoding

Manchester Encoding



Differential Manchester Encoding

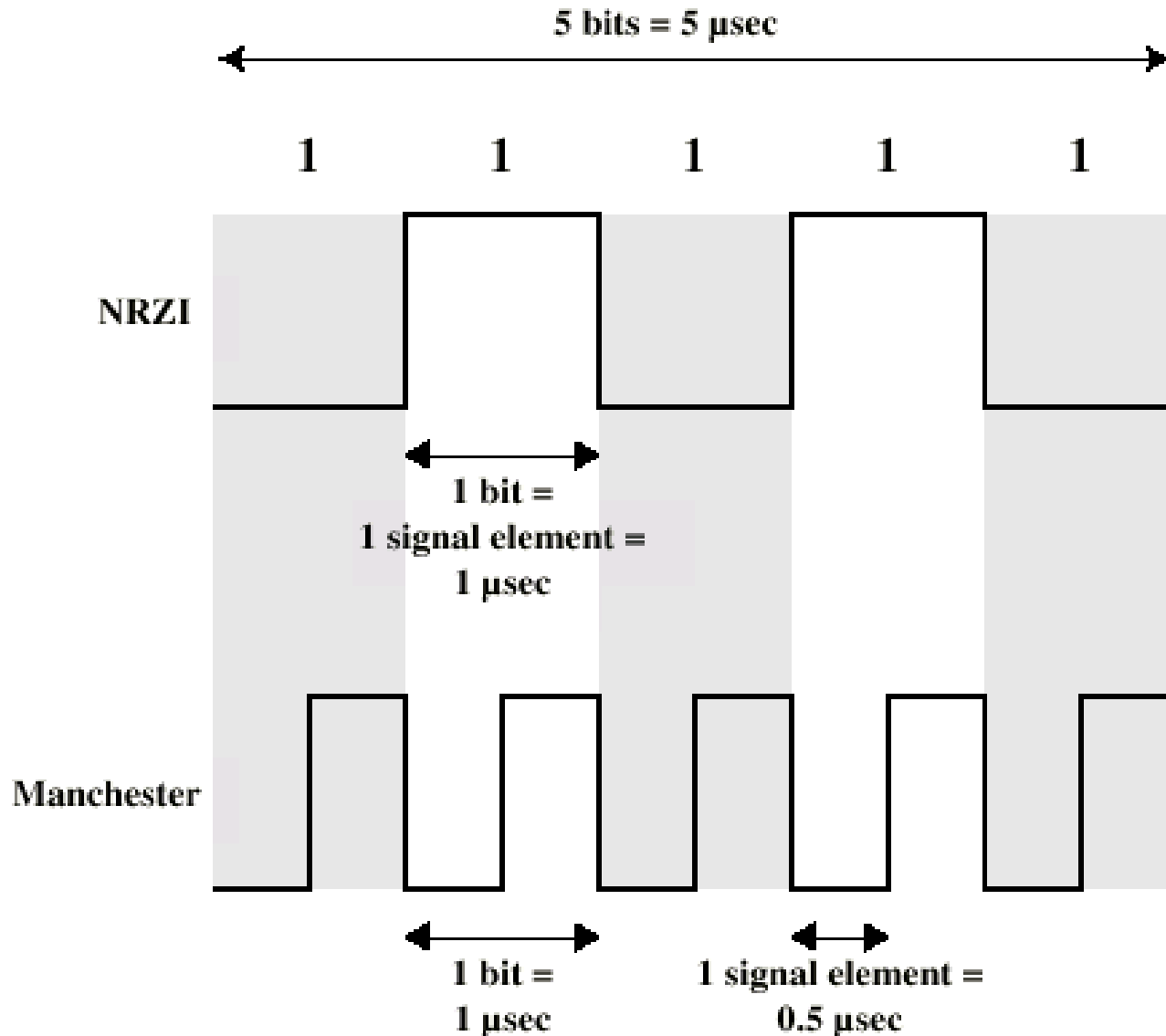
Differential Manchester Encoding



Biphase Pros and Cons

- Con
 - At least one transition per bit time and possibly two
 - Maximum modulation rate is twice NRZ
 - Requires more bandwidth
- Pros
 - Synchronization on mid bit transition (self clocking)
 - No dc component
 - Error detection
 - Absence of expected transition

Modulation Rate



Scrambling

- Use scrambling to replace sequences that would produce constant voltage
- Filling sequence
 - Must produce enough transitions to sync
 - Must be recognized by receiver and replace with original
 - Same length as original
- No dc component
- No long sequences of zero level line signal
- No reduction in data rate
- Error detection capability

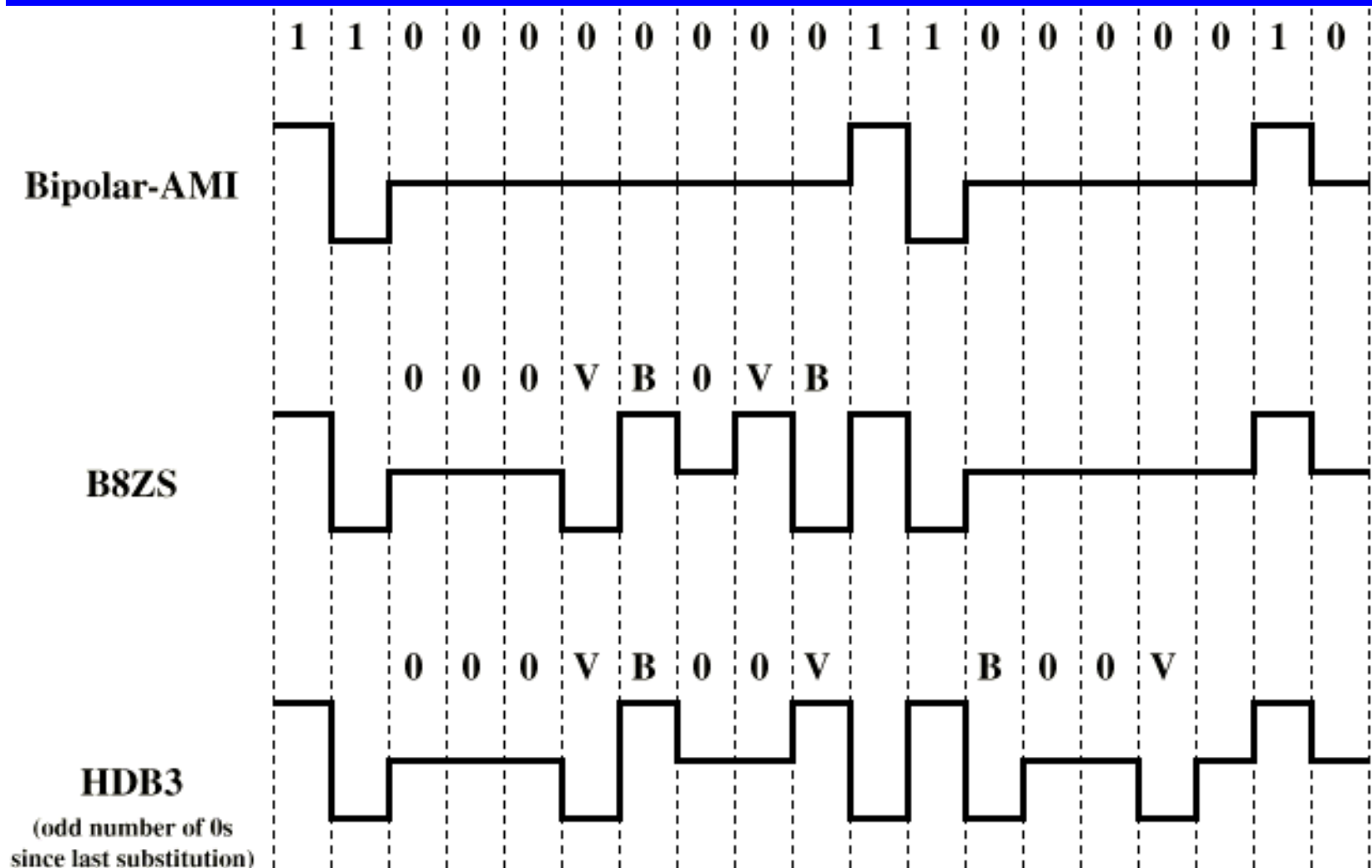
B8ZS

- Bipolar With 8 Zeros Substitution
- Based on bipolar-AMI
- If octet of all zeros and last voltage pulse preceding was positive encode as 000+-0-+
- If octet of all zeros and last voltage pulse preceding was negative encode as 000-+0+-
- Causes two violations of AMI code
- Unlikely to occur as a result of noise
- Receiver detects and interprets as octet of all zeros

HDB3

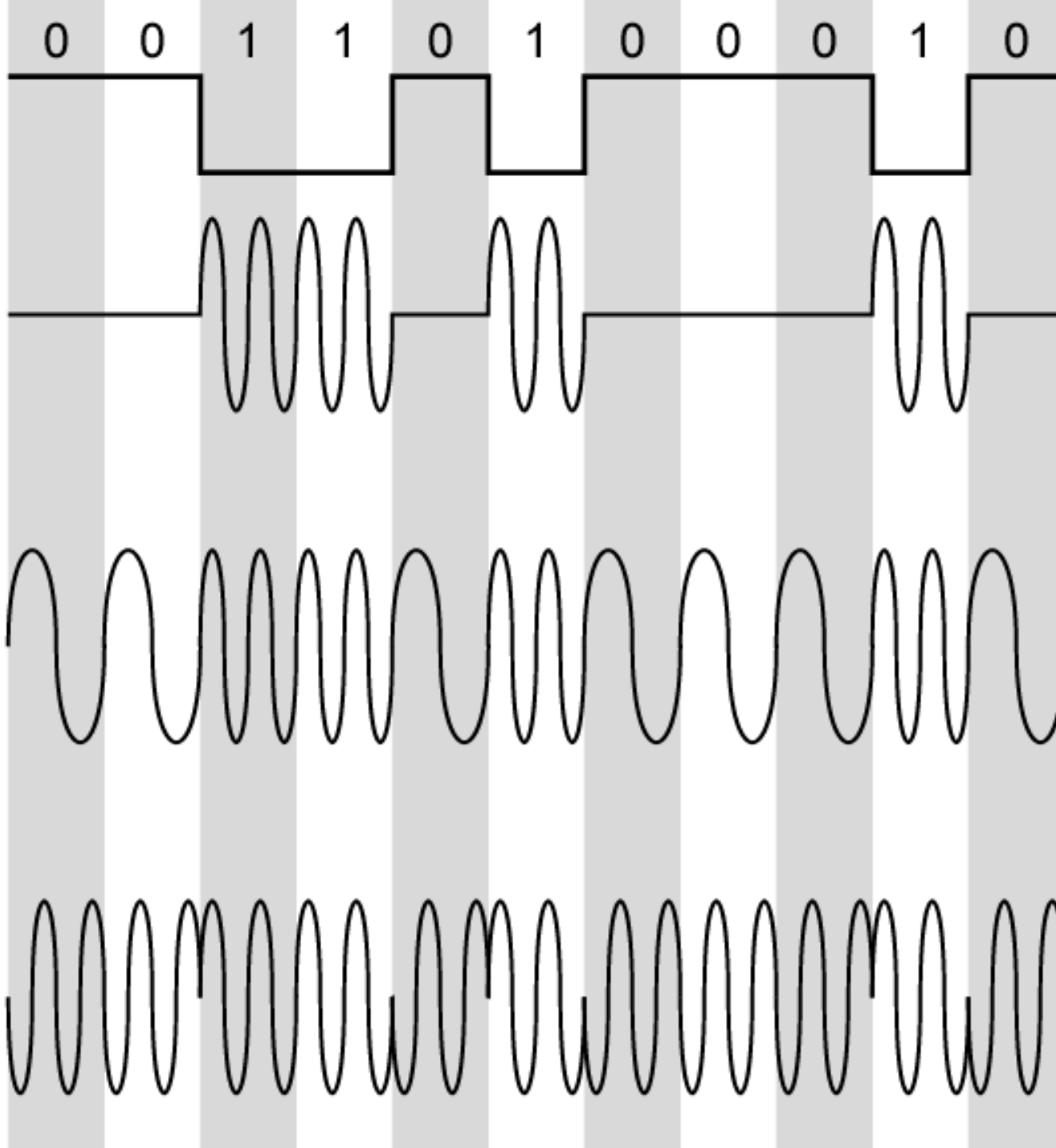
- High Density Bipolar 3 Zeros
- Based on bipolar-AMI
- String of four zeros replaced with one or two pulses

B8ZS and HDB3



Digital Data, Analog Signal

- Public telephone system
 - 300Hz to 3400Hz
 - Use modem (modulator-demodulator)
- Amplitude shift keying (ASK)
- Frequency shift keying (FSK)
- Phase shift keying (PK)



Amplitude Shift Keying

- Values represented by different amplitudes of carrier
- Usually, one amplitude is zero
 - i.e. presence and absence of carrier is used
- Susceptible to sudden gain changes
- Inefficient
- Up to 1200bps on voice grade lines
- Used over optical fiber

Binary Frequency Shift Keying

- Most common form is binary FSK (BFSK)
- Two binary values represented by two different frequencies (near carrier)
- Less susceptible to error than ASK
- Up to 1200bps on voice grade lines
- High frequency radio
- Even higher frequency on LANs using co-ax

Multiple FSK

- More than two frequencies used
- More bandwidth efficient
- More prone to error
- Each signalling element represents more than one bit

FSK on Voice Grade Line

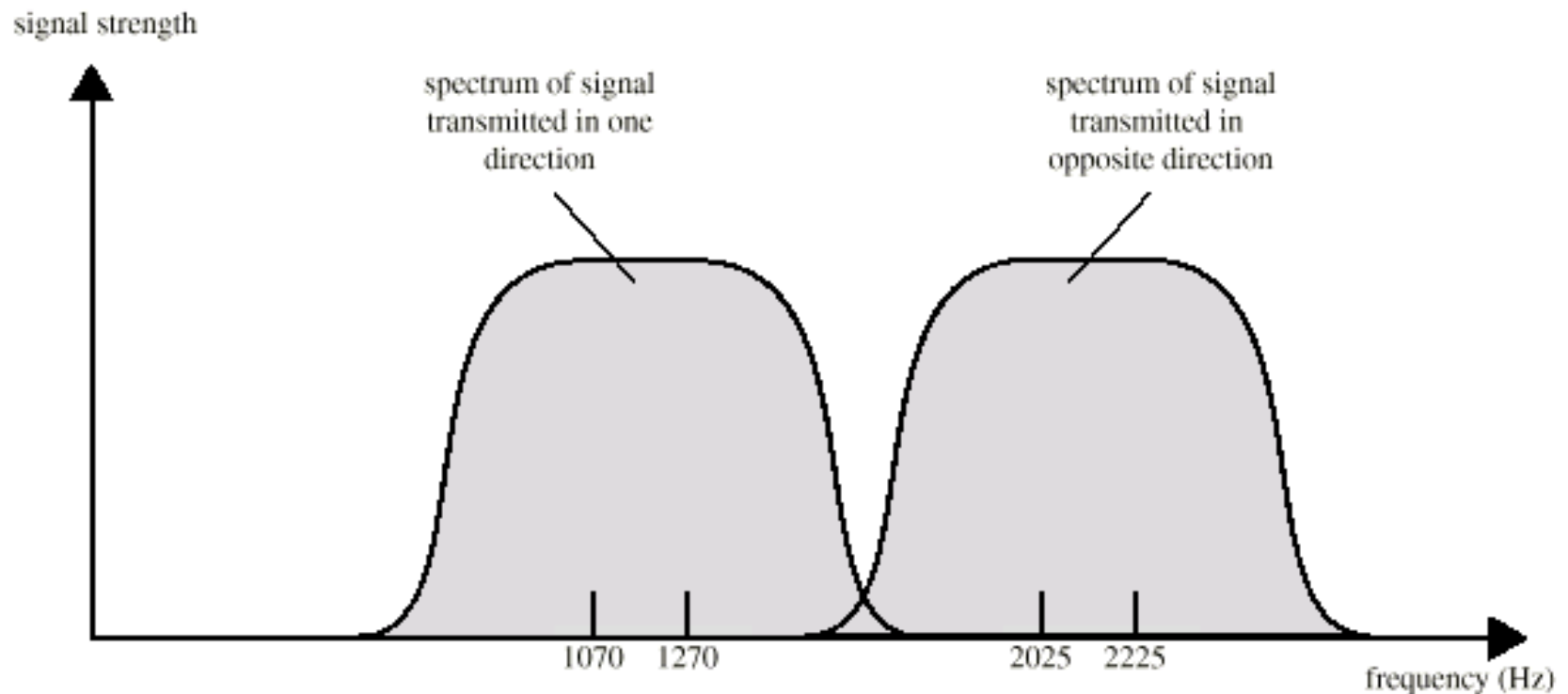
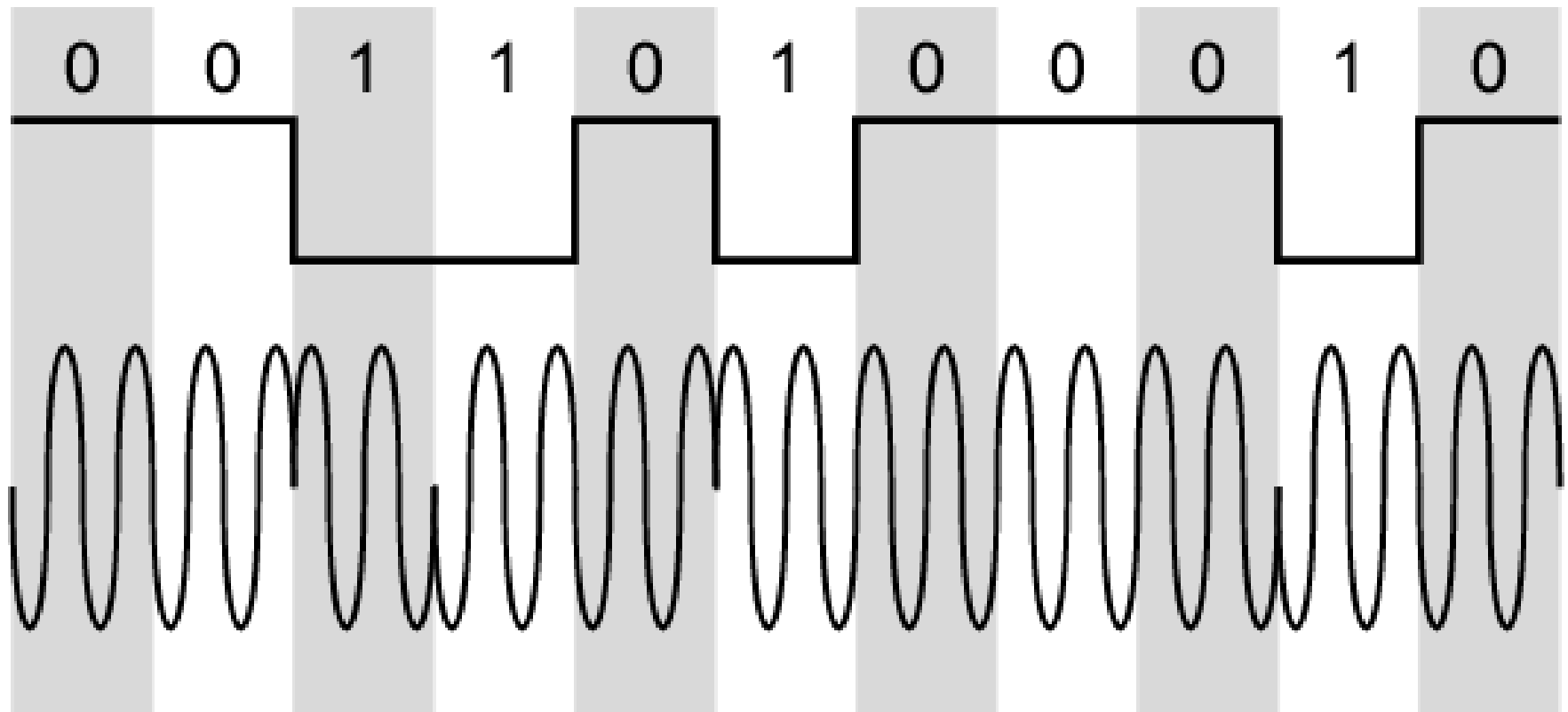


Figure 5.8 Full-Duplex FSK Transmission on a Voice-Grade Line

Phase Shift Keying

- Phase of carrier signal is shifted to represent data
- Binary PSK
 - Two phases represent two binary digits
- Differential PSK
 - Phase shifted relative to previous transmission rather than some reference signal

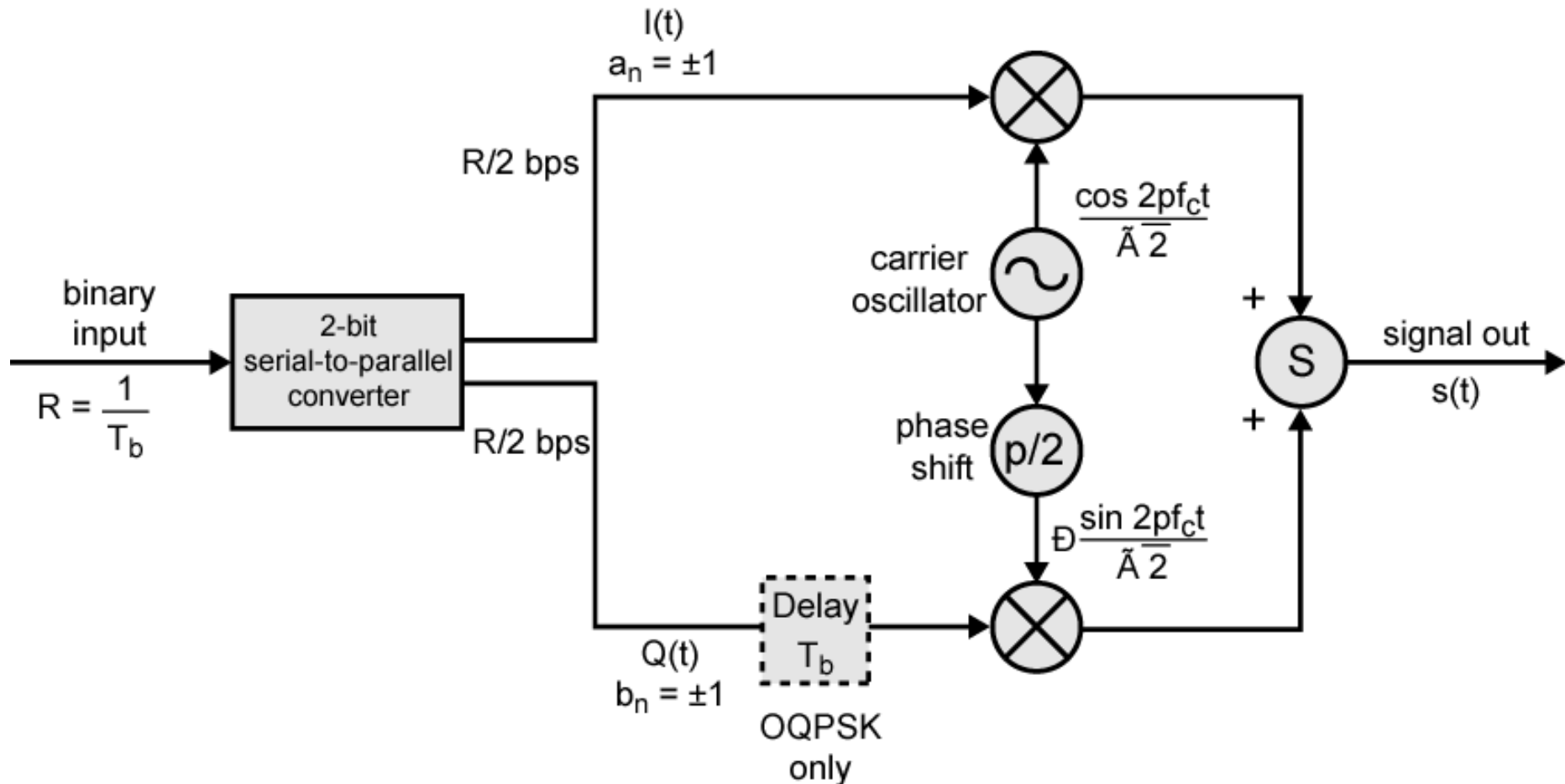
Differential PSK



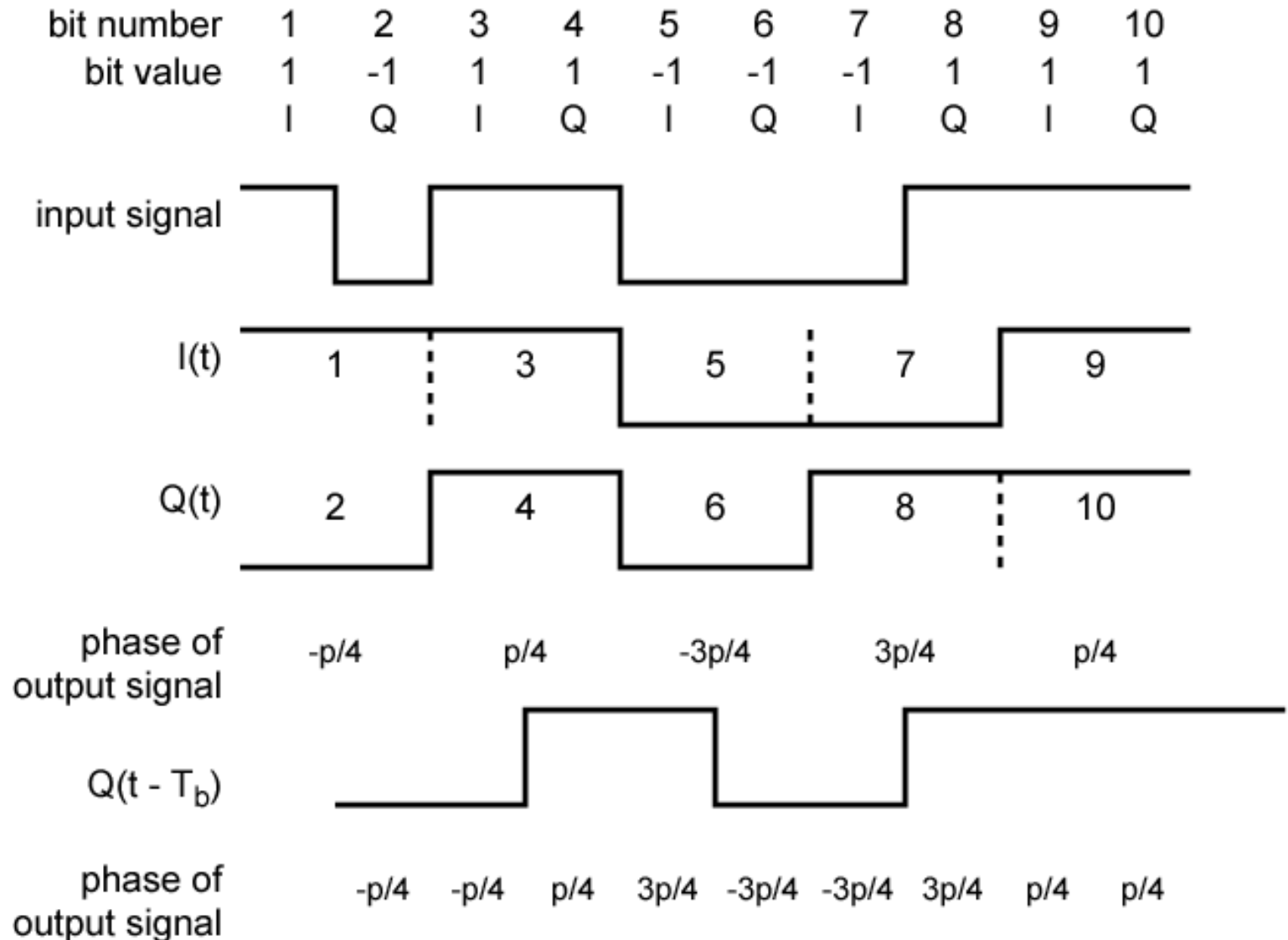
Quadrature PSK

- More efficient use by each signal element representing more than one bit
 - e.g. shifts of $\pi/2$ (90°)
 - Each element represents two bits
 - Can use 8 phase angles and have more than one amplitude
 - 9600bps modem use 12 angles , four of which have two amplitudes
- Offset QPSK (orthogonal QPSK)
 - Delay in Q stream

QPSK and OQPSK Modulators



Examples of QPSF and OQPSK Waveforms



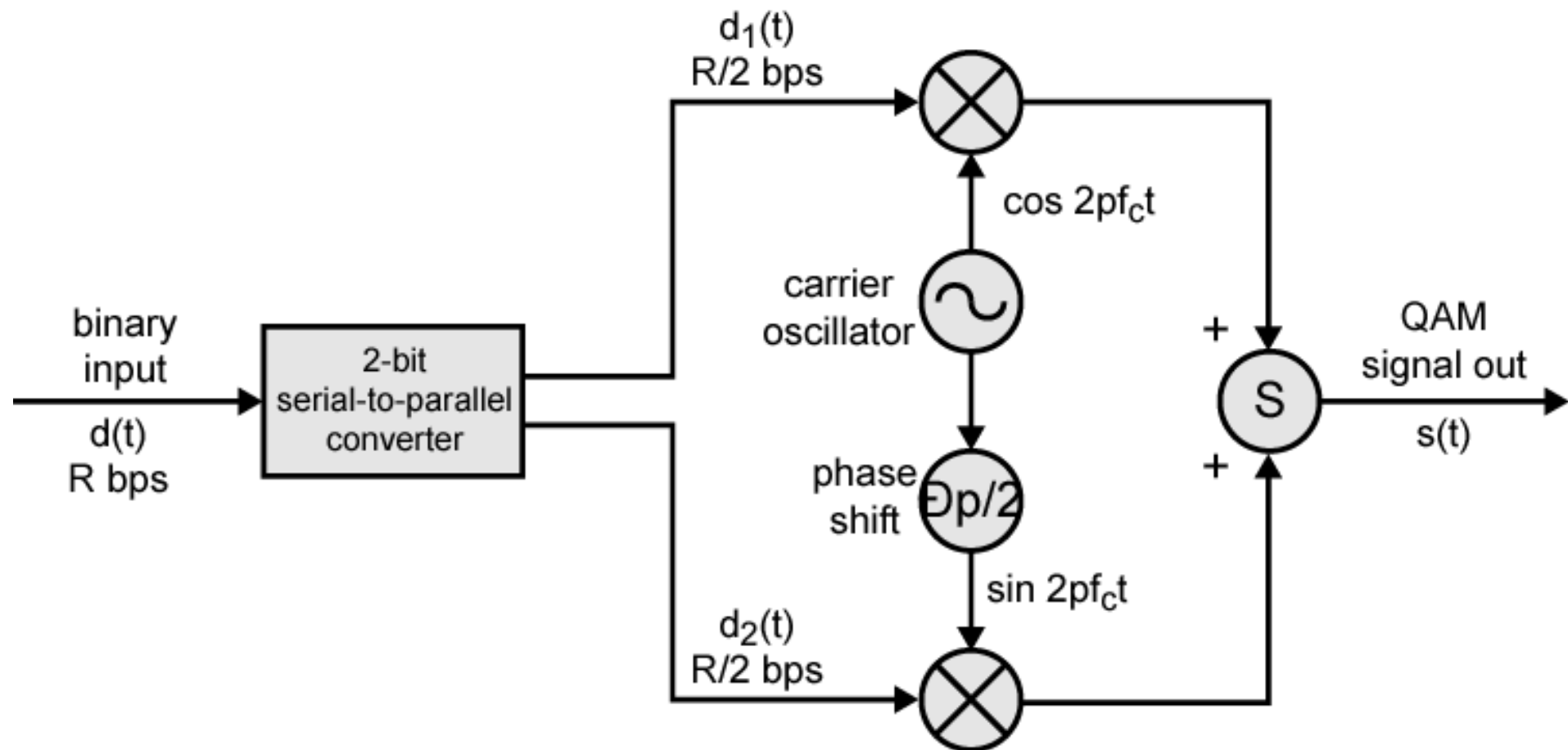
Performance of Digital to Analog Modulation Schemes

- Bandwidth
 - ASK and PSK bandwidth directly related to bit rate
 - FSK bandwidth related to data rate for lower frequencies, but to offset of modulated frequency from carrier at high frequencies
 - (See Stallings for math)
- In the presence of noise, bit error rate of PSK and QPSK are about 3dB superior to ASK and FSK

Quadrature Amplitude Modulation

- QAM used on asymmetric digital subscriber line (ADSL) and some wireless
- Combination of ASK and PSK
- Logical extension of QPSK
- Send two different signals simultaneously on same carrier frequency
 - Use two copies of carrier, one shifted 90°
 - Each carrier is ASK modulated
 - Two independent signals over same medium
 - Demodulate and combine for original binary output

QAM Modulator



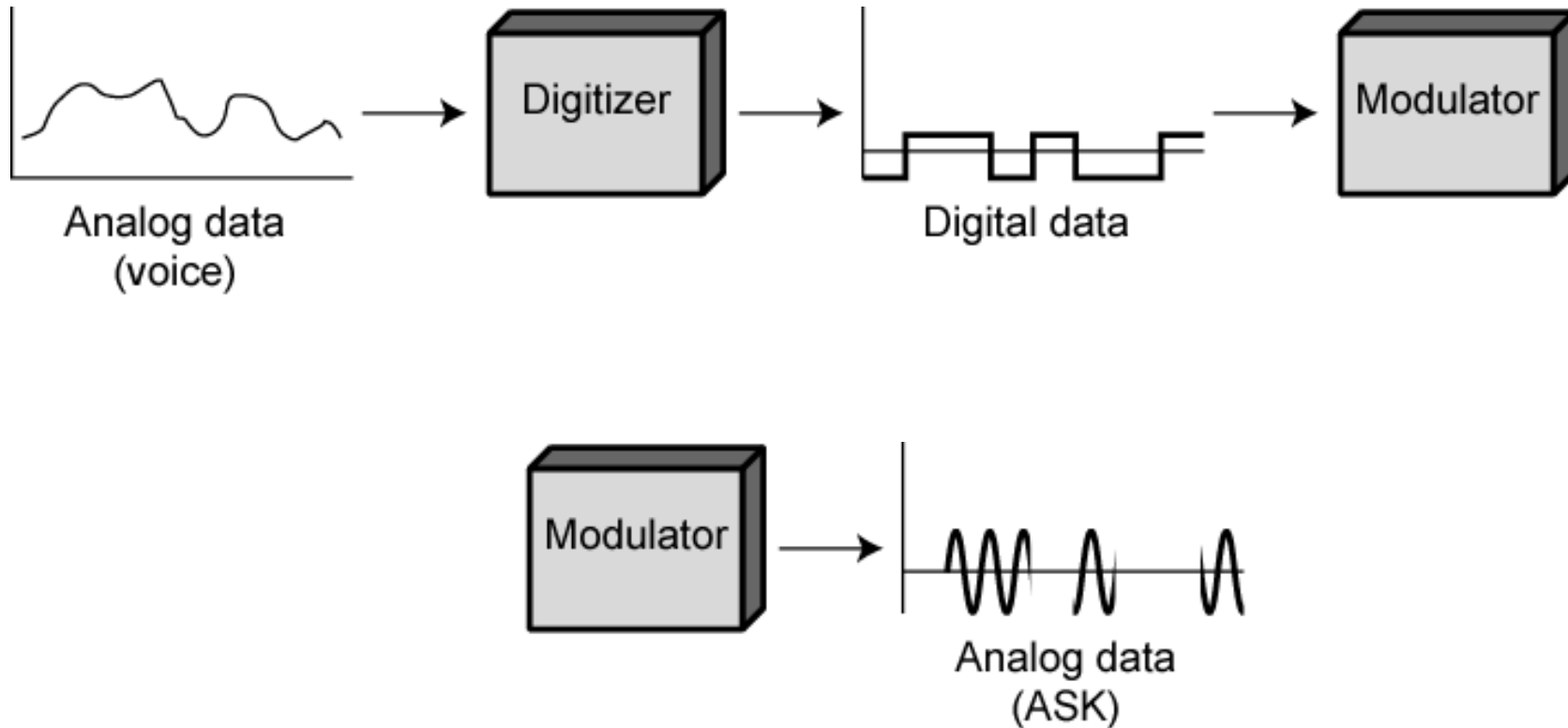
QAM Levels

- Two level ASK
 - Each of two streams in one of two states
 - Four state system
 - Essentially QPSK
- Four level ASK
 - Combined stream in one of 16 states
- 64 and 256 state systems have been implemented
- Improved data rate for given bandwidth
 - Increased potential error rate

Analog Data, Digital Signal

- Digitization
 - Conversion of analog data into digital data
 - Digital data can then be transmitted using NRZ-L
 - Digital data can then be transmitted using code other than NRZ-L
 - Digital data can then be converted to analog signal
 - Analog to digital conversion done using a codec
 - Pulse code modulation
 - Delta modulation

Digitizing Analog Data



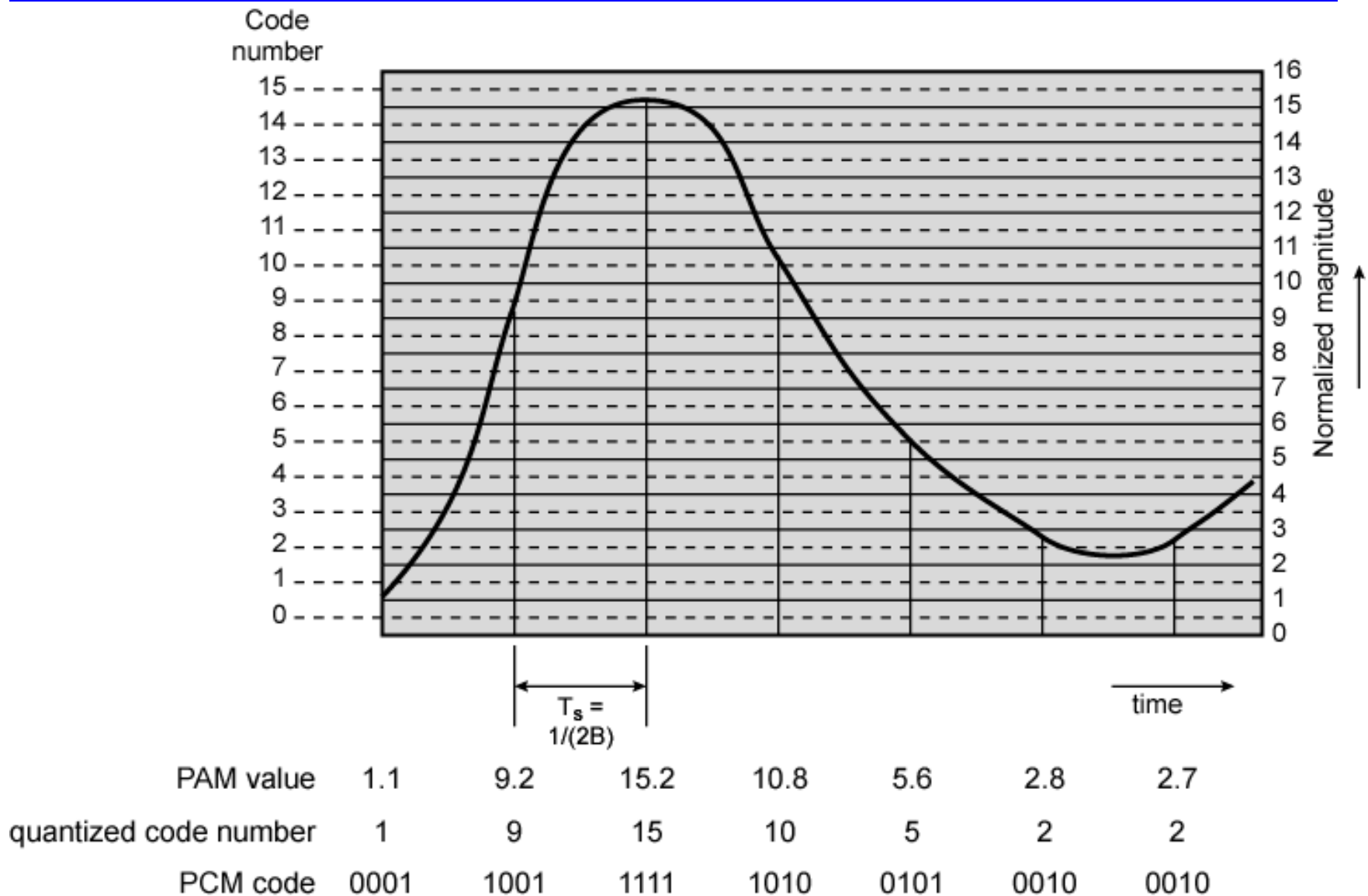
Pulse Code Modulation(PCM) (1)

- If a signal is sampled at regular intervals at a rate higher than twice the highest signal frequency, the samples contain all the information of the original signal
 - (Proof - Stallings appendix 4A)
- Voice data limited to below 4000Hz
- Require 8000 sample per second
- Analog samples (Pulse Amplitude Modulation, PAM)
- Each sample assigned digital value

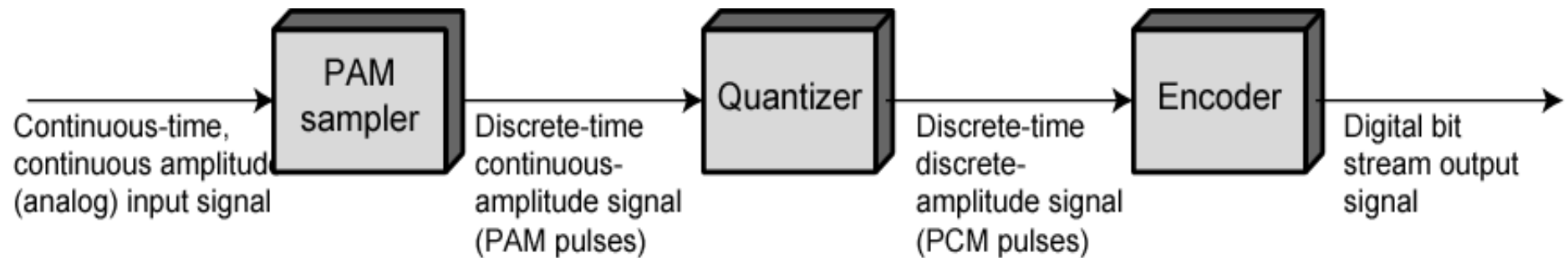
Pulse Code Modulation(PCM) (2)

- 4 bit system gives 16 levels
- Quantized
 - Quantizing error or noise
 - Approximations mean it is impossible to recover original exactly
- 8 bit sample gives 256 levels
- Quality comparable with analog transmission
- 8000 samples per second of 8 bits each gives 64kbps

PCM Example



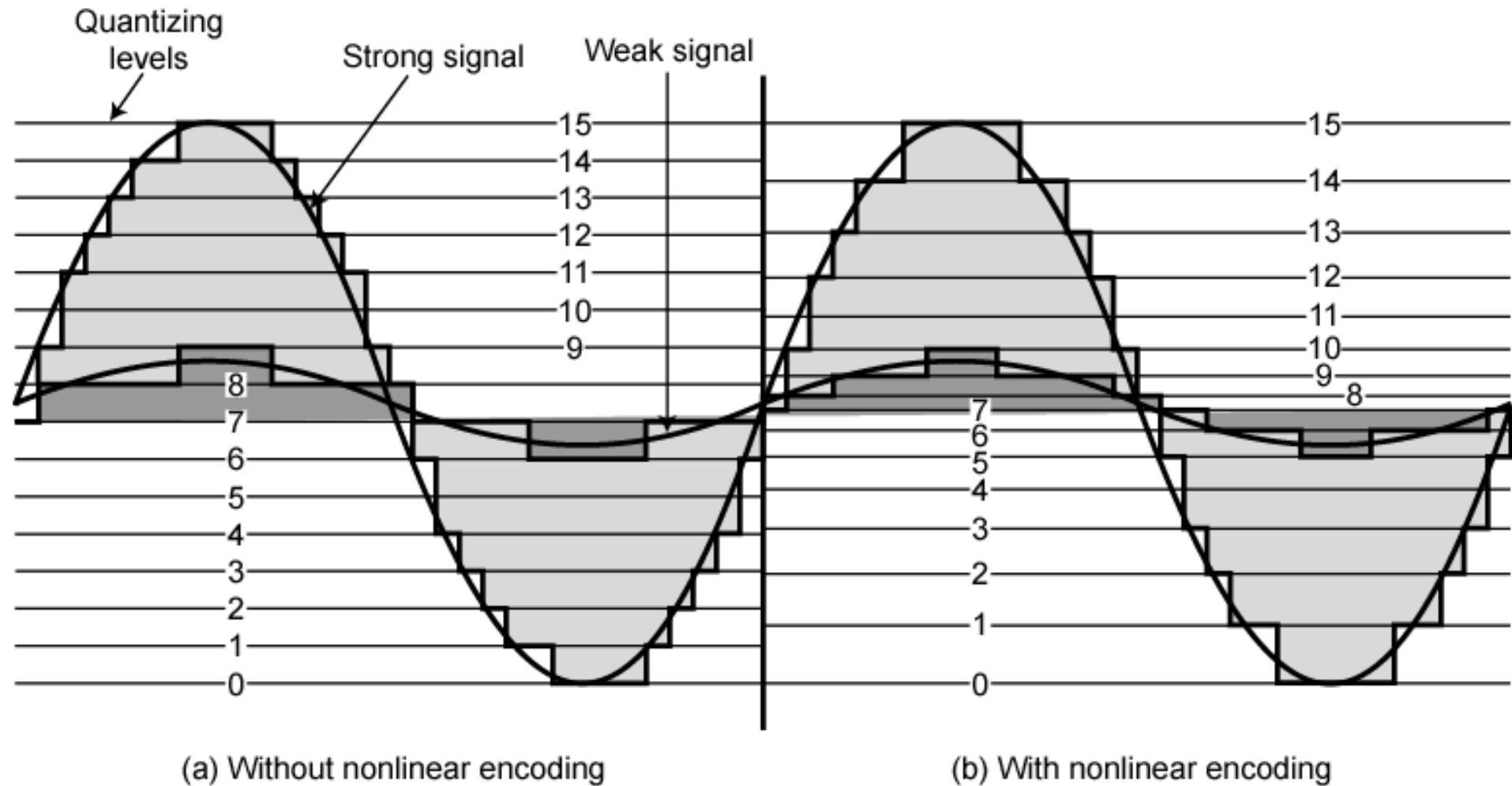
PCM Block Diagram



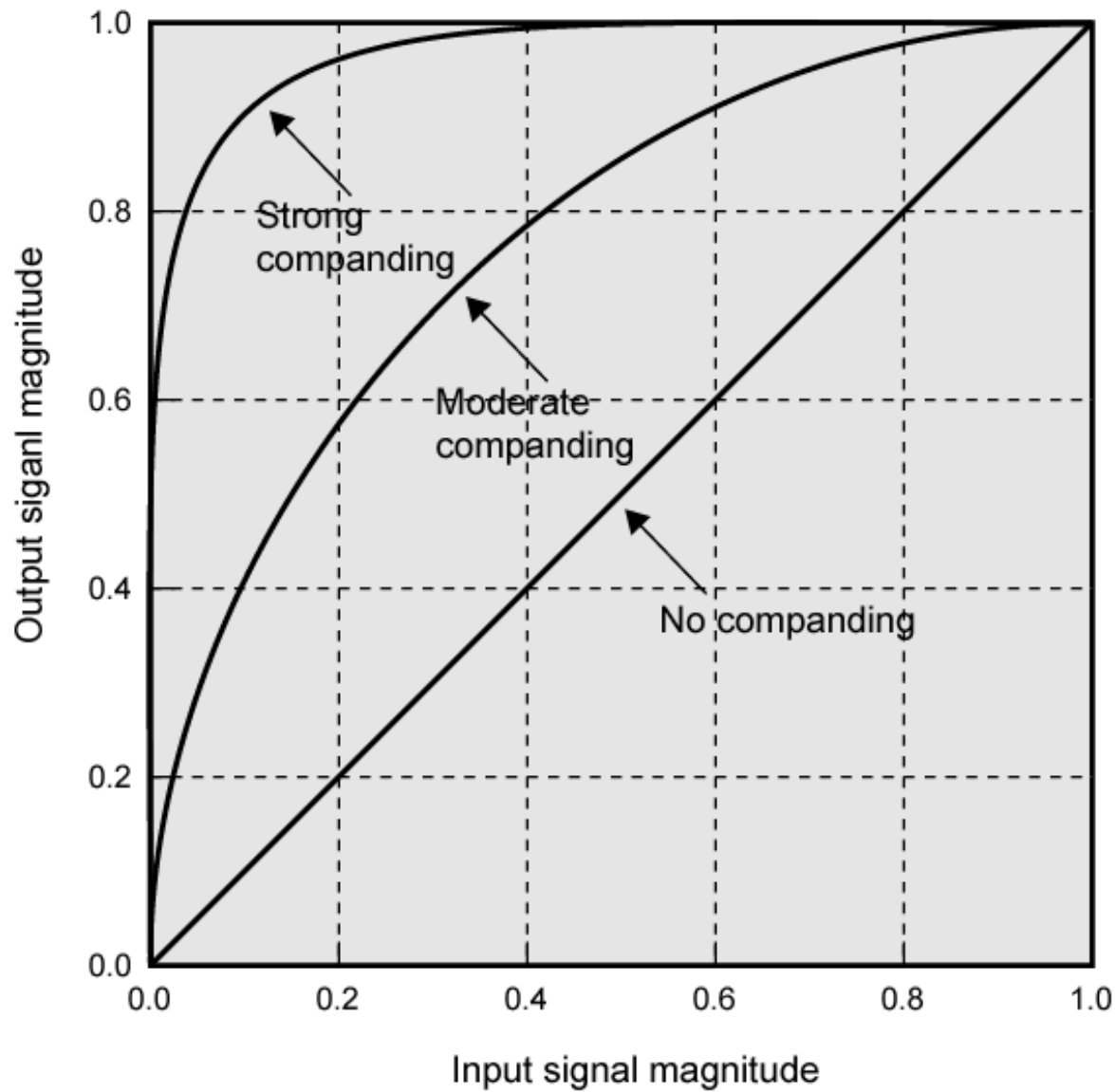
Nonlinear Encoding

- Quantization levels not evenly spaced
- Reduces overall signal distortion
- Can also be done by companding

Effect of Non-Linear Coding



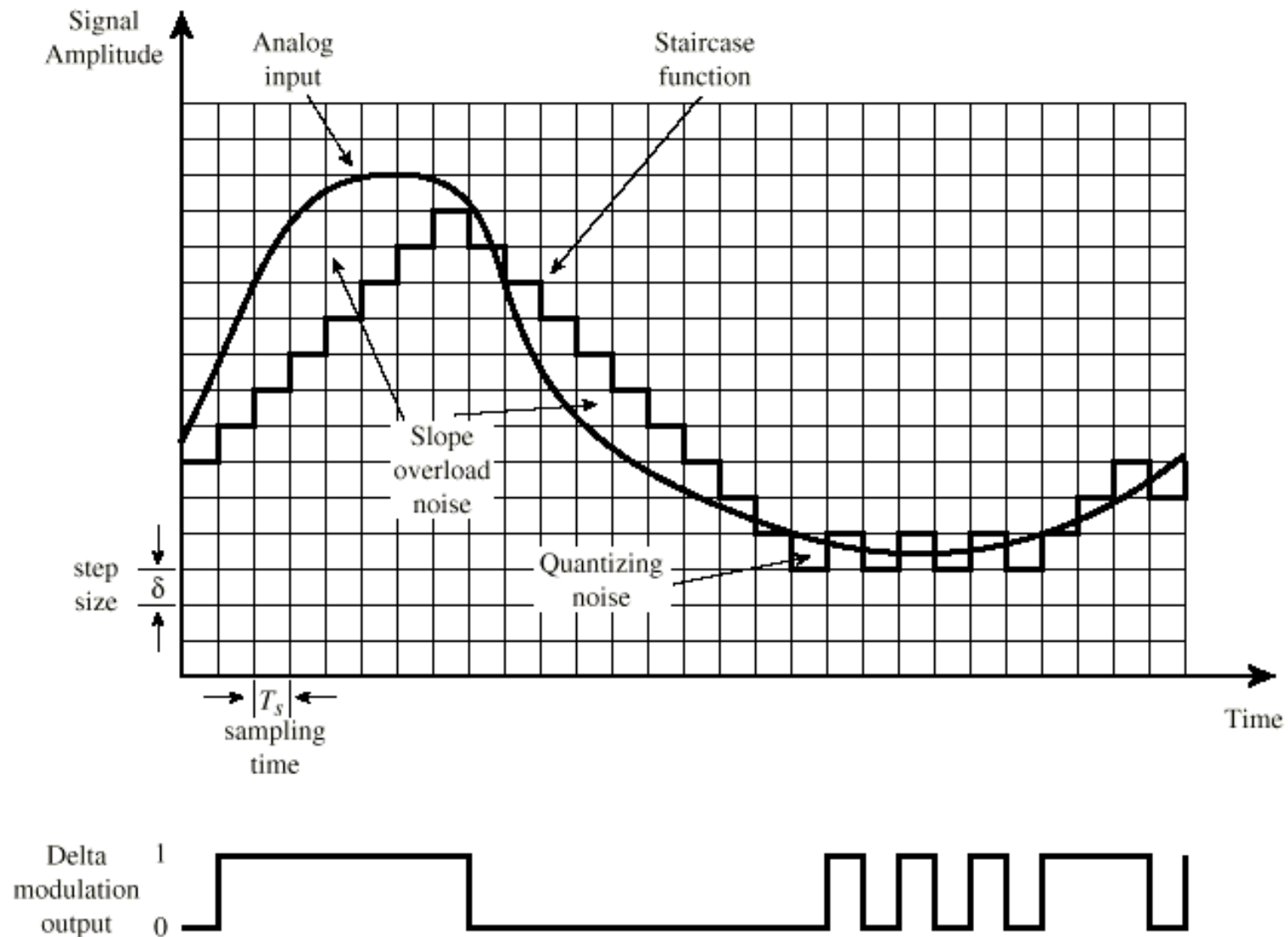
Typical Companding Functions



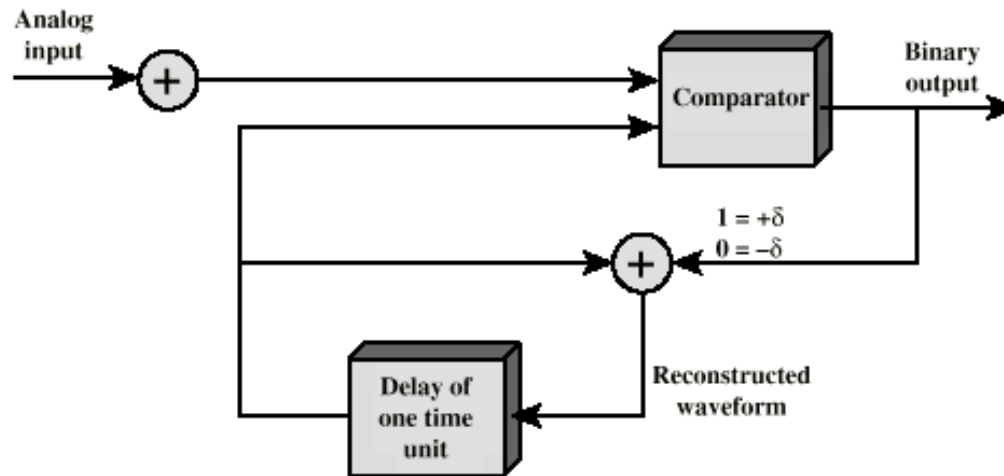
Delta Modulation

- Analog input is approximated by a staircase function
- Move up or down one level (δ) at each sample interval
- Binary behavior
 - Function moves up or down at each sample interval

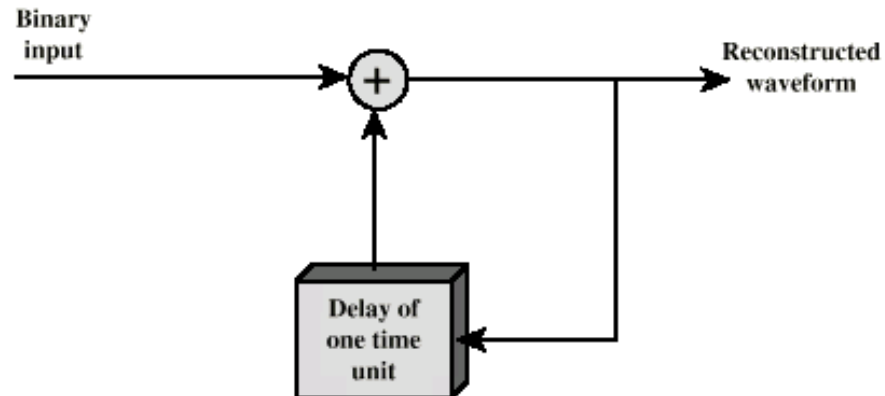
Delta Modulation - example



Delta Modulation - Operation



(a) Transmission



(b) Reception

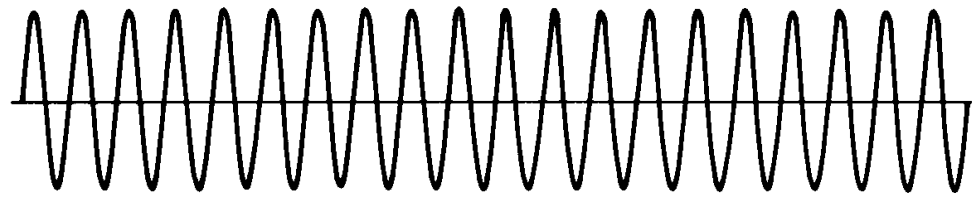
Delta Modulation - Performance

- Good voice reproduction
 - PCM - 128 levels (7 bit)
 - Voice bandwidth 4khz
 - Should be $8000 \times 7 = 56\text{kbps}$ for PCM
- Data compression can improve on this
 - e.g. Interframe coding techniques for video

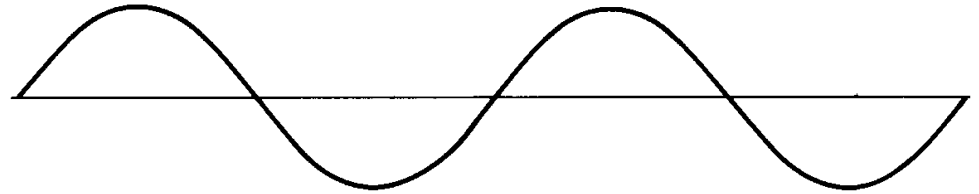
Analog Data, Analog Signals

- Why modulate analog signals?
 - Higher frequency can give more efficient transmission
 - Permits frequency division multiplexing (chapter 8)
- Types of modulation
 - Amplitude
 - Frequency
 - Phase

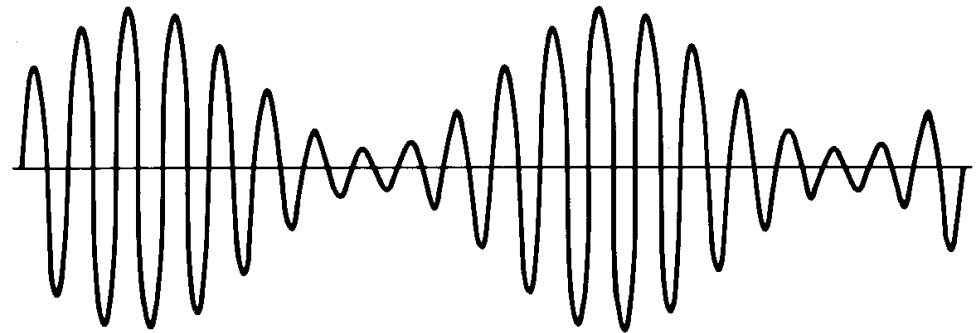
Analog Modulation



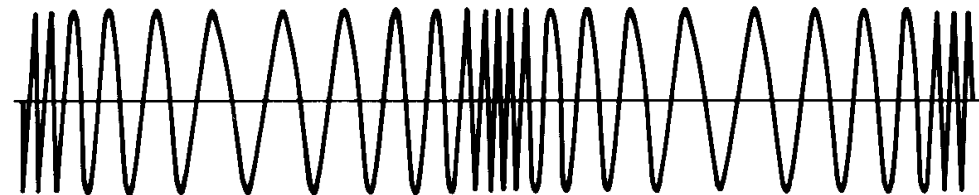
Carrier



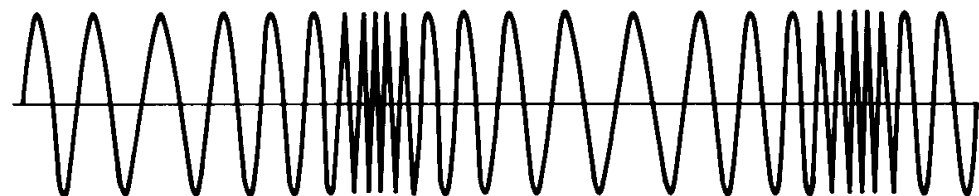
Modulating sine-wave signal



Amplitude-modulated (DSB-TC) wave



Phase-modulated wave



Frequency-modulated wave

Required Reading

- Stallings chapter 5